Contract report for the
Horticultural Development Council

Asparagus: validation of *AspireNZ* for the UK

FV 271

March 2007

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Project number:	FV 271
Report:	Final report, March 2007
Previous reports:	Annual report, March 2006
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Location of project:	Commercial holdings and laboratory facilities at ADAS Arthur Rickwood
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Date project commenced:	1 October 2005
Date completion due:	31 March 2007
Key words:	Asparagus, ***Aspire***, decision support system, root carbohydrates, yield

The results and conclusions in this report are based on a series of experiments conducted over two years. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

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AUTHENTICATION

I declare that this work was done under my supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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1 GROWER SUMMARY

1.1 Headline

The ***AspireUK*** decision support system is now available on the internet for use by the UK asparagus industry (www.aspireuk.org) following a 2½-year research project. It provides a tool that growers can use to improve crop performance, based on better knowledge and understanding of the role of root carbohydrate in the yield physiology of asparagus.

1.2 Background and expected deliverables

Asparagus is a perennial crop with a large storage root system. The performance and economic life of a crop is driven by the gain and loss of soluble carbohydrate (CHO) in the storage root system. A characteristic pattern of accumulation and depletion of CHO in the roots occurs during the crop's annual cycle (Figure 1.1). Deviations from the normal pattern can indicate that performance is below optimum and can be used to help diagnose and resolve problems, and sustain crop performance. Despite its importance, information about root CHO content and the significance of CHO levels is seldom available to asparagus growers. To address this problem, the New Zealand Institute for Crop & Food Research (NZICFR) has developed a web-based decision support system (***AspireNZ***) that can be used to improve asparagus crop performance, through better knowledge and management of root CHO dynamics.

The ***Aspire*** system is already being used by subscribing asparagus growers in New Zealand and North America.

The overall aim of this project is to develop and deploy a decision support system tailored to UK environmental conditions and asparagus production methods, based on a prototype system (***AspireNZ***) developed in New Zealand.

The specific objectives are:

1. Prepare protocols and procedures for crop sampling.
2. Sample crops at selected key times in crop growth over two growing seasons.
3. Collate and incorporate technical information required for ***AspireUK*** into the existing prototype.
4. Develop prototype software for the ***AspireUK*** decision support system.
5. Develop and deploy commercially a final version of ***AspireUK.***
6. Disseminate information about ***AspireUK*** to UK asparagus growers.

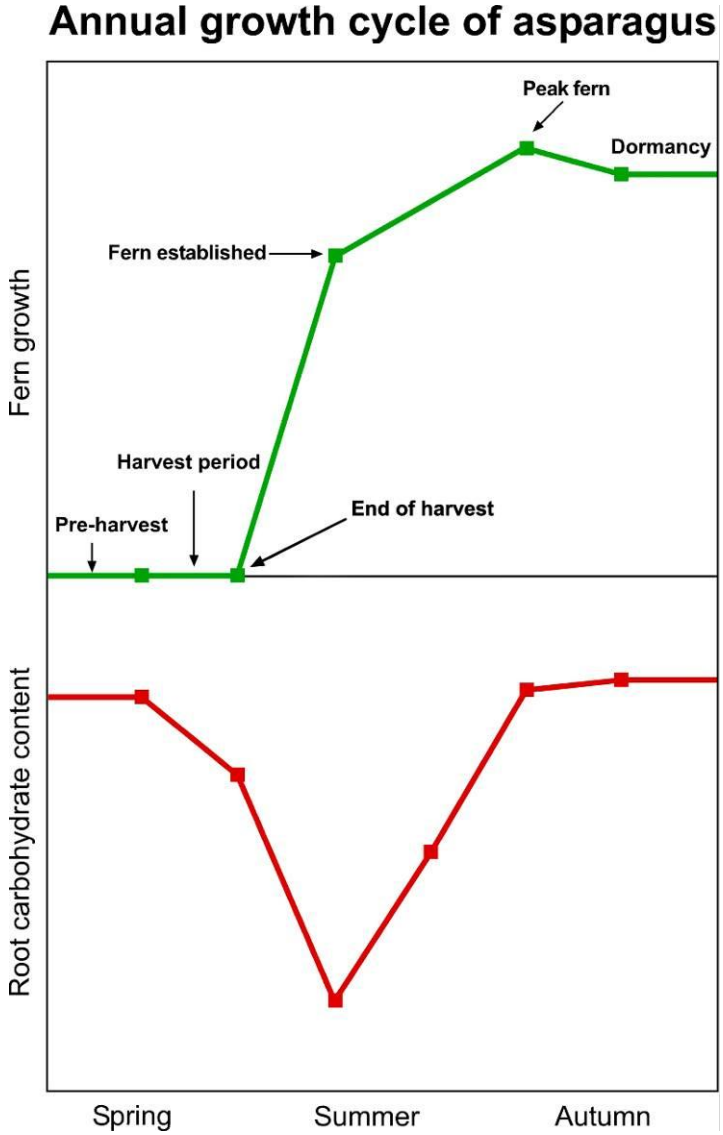


Figure 1.1 Annual growth cycle of asparagus

1.3 Summary of the project and main conclusions

1.3.1 Site selection

Twelve asparagus crops were monitored over a two-year period, with four crops in each of the main production areas of England (east, south and west). Four of the sites (E2, E4, S4 and W1) were categorised as young crops, planted in 2002 or later, with a first full harvest planned for 2005. The others were classed as established crops, having previously had at least one full harvest. Dutch varieties were grown at all of the sites except E4 where an American variety, Jersey Giant, was grown. The previous performance of the crops in terms of yield and fern growth was contrasting. Growers noted various production constraints including phytophthora (S1, S2 and E1) and stemphylium (e.g. W4). Polythene covers to promote early harvesting were used on crop W1.

1.3.2 Crop sampling

The sampling schedule for the duration of the project is shown in Table 1.1.

Table 1.1. Sampling times and measurements taken during the ***AspireUK*** project

Sampling Time	Measurement					
	Root CHO		Fern Biomass		Root Biomass	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Dormancy, Pre-Harvest	✓	✓				
End of Spear Harvest	✓	✓				
End of Fern Establishment	✓	✓	✓	✓		
Peak of Fern Growth	✓	✓	✓	✓		
Dormancy, End of Autumn	✓	✓			✓	

1.3.3 Key crop performance indicators

The state and performance of the 12 crops varied widely. By 2006 their ages since planting were from three to 10 years, so they ranged from young, establishing crops to established, mature ones.

By the end of 2006, the main indicator of the below-ground status of the crops (root biomass) varied by more than three-fold. A crop's root biomass is determined by the product of average size per plant (measured at the end of 2005) and the number of plants per hectare (estimated in 2005 and 2006). Both factors varied among the 12 monitored crops. Plants had been lost from most of the crops. In some cases large losses had occurred, with from 6 to 43% lost since establishment. As a result, populations ranged from about 11,400 to 21,100 plants per hectare, and structural dry weights varied from about 3.4 to 10.5 t/ha. CHO and total weights ranged from 3.2 to 14.8 t/ha and 7.3 to 25.3 t/ha respectively.

Spear and fern growth were the main above-ground indicators of crop performance. In both years spear yields ranged from about 2,000 to over 6,000 kg/ha. These yields were produced over harvest periods from 46 to 59 days. A notable exception was one crop (W1), which produced 6,600 kg/ha over an 89 day harvest period in 2005. The average rate of spear yield production during harvest, which is driven mainly by temperature and the availability of CHO for spear growth, differed three-fold among the 12 crops with a range from about 40 to 120 kg/ha/day. The average spear yield of individual plants during harvest ranged from about 0.1 to 0.3 kg. This meant that each plant produced from 5 to 15 spears during the harvest period, assuming an average weight of 20 g per spear.

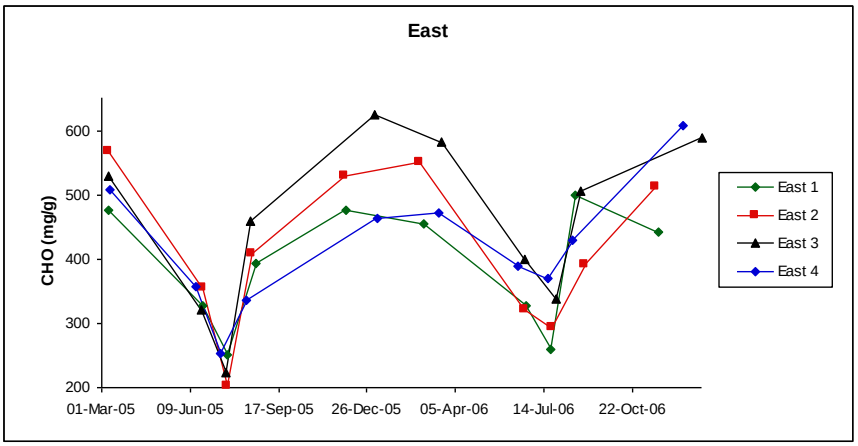
Fern growth was generally greater in 2005 than in 2006, perhaps because of dry conditions during the fern establishment period in 2006. In 2005 it ranged from about 1,500 to 5,900 kg/ha and in 2006 the range was about 1,100 to 5,100 kg/ha. Good, but not excessive, fern growth is needed to fully recharge root CHO content, and inadequate fern growth was unlikely to have limited recharge in most of the 12 crops.

1.3.4 Root carbohydrates

Root CHO contents are presented in Figure 1.2. For almost all of the test crops they followed the expected pattern of depletion and accumulation as demonstrated from previous work in New Zealand and the USA. In general, CHO content was always high at the start of harvest, declined during harvest, declined further to a minimum level during fern establishment, and then recovered again during fern growth to reach a high level by the end of autumn. Most crops deviated from the 'ideal' pattern in some way and there was much variation in the root CHO values at various times during the cycle. There were many possible reasons for the variation that depended on the circumstances of each crop, but the reasons can be separated into two general categories:

- Differences associated with the size of the root system. Root biomass varies widely among crops. The size of the system determines the capacity of a crop to accumulate and store CHO, and therefore it influences the extent of CHO fluctuations during the annual cycle. In general, crops with small root systems (i.e. small CHO storage capacity) exhibit larger CHO content fluctuations than crops with big root systems, even though the quantity of stored CHO maybe considerably greater in the latter.
- Difference attributable to particular agronomic conditions in individual crops. Many differences are caused by effects of management and environmental factors that can be identified readily. Examples are reduced CHO accumulation caused by the effects of an unfavourable growing season, low fern vigour, and weed, pest and disease problems during fern growth.

A



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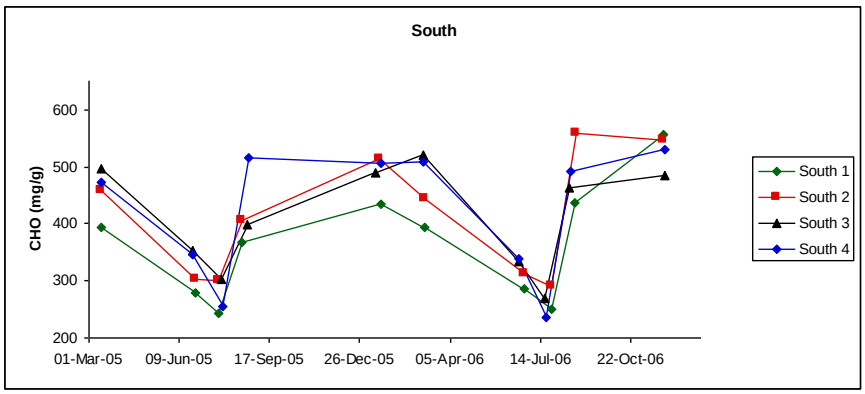

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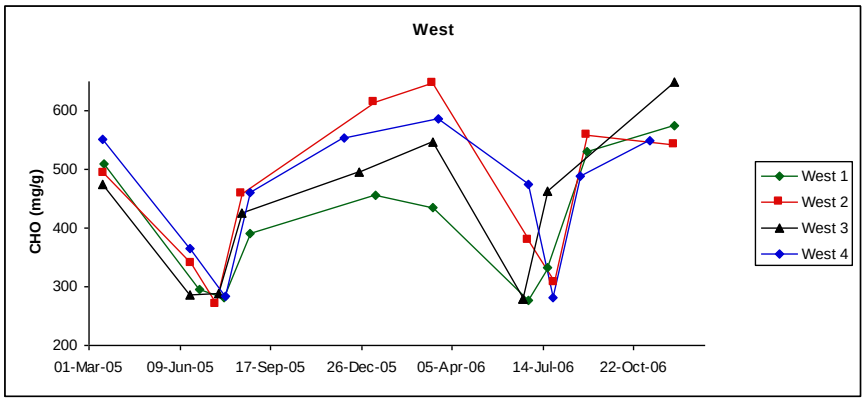

Figure 1.2. Root CHO content values for 12 asparagus crops sampled at five stages of crop growth in 2005 and 2006, in three regions, east (A), south (B) and west (C)

1.3.5 Crop profiles

Information about crop performance and root CHO dynamics was analysed to produce a profile of each crop. Profiles of five example crops are given here to illustrate the combinations of features that were associated with high and low yields.

E2: A young, healthy vigorous crop that was one of the highest yielding in both years. The root biomass was large for a young crop indicating excellent establishment and vigour, and as a result, plant loss has been low to date. It also had good fern growth in both years. It showed a close to ideal pattern of CHO accumulation and depletion, commencing at 550 mg/g CHO or more pre-harvest in both seasons. After the first full harvest in 2005 (53 days), CHO levels dropped to around 200 mg/g by the end of fern establishment, which is normal for a young crop at this stage in the season. CHO recharge was satisfactory and exceeded 500 mg/g by dormancy. A similar pattern was observed in 2006 with a higher yield taken during a 51-day harvest period.

W1: A young crop that was one of the highest yielding in both sampling years. It has been harvested intensively during its early years and as a result, the root biomass is small because individual plants have not expanded their root systems and already 20% of plants have been lost by year 3. Harvests started early in both years through use of polythene covers and were extended beyond the normal end of harvest date in 2005 (89 days). Following the extended harvest, fern growth was poor and as a result, CHO accumulation by dormancy (457 mg/g) was well below optimum for a small root system. In 2006 a shorter harvest (63 days) allowed the opportunity for greater CHO recharge and crop recovery during fern growth. The crop will need careful management if high yields are to be sustained.

W4: An established, vigorous crop with the largest root system and strong fern growth. It had few pest and disease constraints and minimal plant loss. Despite these positive features, yields were good but not exceptional. The crop showed a close to ideal pattern of CHO accumulation and depletion, except that values were much higher than they needed to be at the end of harvest (365 and 475 mg/g in 2005 and 2006, respectively) based on ***AspireUK*** benchmarks. These high values, combined with the fact that the harvest durations were only about 50 days, suggest a missed opportunity for higher yields. Harvests could have been extended with little risk of adversely affecting CHO recovery and crop health.

E4: A young establishing crop with the smallest root biomass mainly because it has the smallest individual plant size of all the crops. Fern biomass was below average and growth was characterised by toppling, breakage and subsequent death of larger ferns. Spear yield was poor especially in 2006 when it was the lowest of all the crops. CHO dynamics followed the usual pattern but the amplitude of gains and losses was less than expected for a

crop with such a small root system. A high CHO value at the end of 2006 (608 mg/g) suggests some crop recovery.

W2: A mature crop that has reportedly struggled since establishment and is now in classical decline. It has average root biomass, which is decreasing as plants are lost (43% lost by 2006). Fern growth was below average with damage caused by asparagus beetle and stemphylium purple spot in both years. Low yields were characterised by thin spears with 75% less than 10 mm diameter. The CHO content followed the usual pattern, with a large range reflecting the small size of the root system. A CHO value of 647 mg/g in March 2006 was the highest pre-harvest value recorded in all the crops. Root CHO content reached a maximum early in fern growth in 2006, then declined possibly due to the damaging effects of stemphylium and beetle.

1.3.6 Developing AspireUK

During the project, a prototype of ***AspireUK*** (following the ***AspireUS*** model) was available on the Internet at www.aspireuk.org, providing background information on the project. Project participants including collaborating growers were given a Username and Password to allow access for web-site testing and familiarisation during the project.

Following completion of data collection, the prototype ***Aspire*** system was adapted for UK climate and production conditions in readiness for commercial deployment to the UK asparagus industry.

For each growth stage, the CHO values recorded in the monitored crops were separated into bands from high to low, with each band spanning a 100 mg/g range. This allowed identification 'ideal' values for each growth stage. From these we derived the optimum range of CHO values for each growth stage in UK conditions. In general, the ranges were similar to those determined in other countries. The main exception was that the maximum CHO values achieved both at dormancy and pre-harvest were generally higher in UK crops.

In summary, benchmark CHO values were as follows:

- In general, the target 'full' root CHO content at dormancy and pre-harvest should exceed 550 mg/g. This target is higher than the values in New Zealand and the US.
- Target end of harvest CHO content is within a range of 250-350 mg/g with an ideal end point of about 320 mg/g. This is slightly higher than was set for New Zealand and the US. The higher target in ***AspireUK*** reduces the likelihood of growers prolonging harvest duration too much in the limited UK growing season length.

- The normal range for the end of fern establishment is 200 to 300 mg/g ('empty' root system). It is a less important decision benchmark, but experience in New Zealand and the US is that depletion below 200 mg/g should be avoided.

These CHO values need to be interpreted in relation to each crop, especially taking account of the size of the functional root system. ***AspireUK*** provides interpretations for three general classes of root systems: i) young establishing crops with small but expanding systems, ii) older crops with declining systems, indicated by a high proportion of dead roots and, iii) older crops with large root systems.

In some circumstances ***AspireUK*** suggests that an extended harvest might be possible without harming the crop. This recommendation is given with a proviso that it is important to achieve a balance between CHO targets and the timing of crop development. For example, following a recommendation to continue harvesting beyond the normal end-date should be done in the knowledge that it could affect the prospect of full CHO recovery by the autumn.

The finalised website is now available at www.aspireuk.org.

1.3.7 Commercialisation of AspireUK

AspireUK is now available on the internet for the UK asparagus industry. Useful background information is available on the public section of the website but only registered subscribers can login to the secure section and use the system. Instructions for registration are available on the website.

A commercial arrangement has been established between Hargreaves Plants Ltd and NZICFR to make the system available to UK asparagus growers.

Hargreaves is marketing and supporting ***AspireUK***. In that role it is responsible for:

- Encouraging and helping growers to subscribe to the system and use it.
- Providing administrative support by being the first point of contact for users, registering new users, and collecting subscription fees.
- Providing help-desk support when users have problems operating the system.

The role of the New Zealand Institute for Crop & Food Research is to:

- Provide technical support and education to specialists on topics such as:
  - Understanding the yield physiology of asparagus to aid interpretation of outputs from ***AspireUK***.
  - Procedures for sampling roots and measuring Brix%.
- Operate, maintain and enhance the ***AspireUK*** website in New Zealand.

Key points of the commercial arrangement are:

- There is guaranteed security of each grower's information in the ***AspireUK*** database. The only people with access are the registered user, the system administrator in New Zealand and anyone else authorised by the user.
- ***AspireUK*** is available to growers with no obligation for any other business association with Hargreaves.
- Users are encouraged to seek support from their technical advisors to help interpret outputs from ***AspireUK*** in relation to their own crops.

1.4 Financial benefits

The project will benefit the industry by developing and deploying a tool (relevant to UK production conditions) which, in other asparagus growing regions, is already providing growers with a sound technical basis for making crop management decisions. Based on experiences of asparagus growers in New Zealand and North America, UK growers are expected to benefit from the following potential uses of the ***Aspire*** system:

- Provide better insight into the likely return on investment in pest, disease or weed control measures by indicating how much these factors are influencing CHO accumulation in the roots during fern growth.
- When adequate CHO is available in the roots, confidently extend the harvest season without a deleterious effect on the capacity of a crop to replenish its CHO levels adequately for the next season. For example, a typical UK crop could produce about £400 per ha of extra revenue for every day of harvest beyond the usual end date.
- Enhance the long-term sustainability of a crop by avoiding over-harvesting, especially in the early years. Every additional productive year adds substantially to the return on investment in a crop.
- Plan with more certainty for the next season's harvest by knowing the extent of CHO recharge during the summer and autumn.

1.5 Action points for growers

- Gain understanding of the importance of root system size and especially root CHO content in determining yield in asparagus.
- Develop an appreciation of the potential to improve short and long term crop performance by using root CHO monitoring as a tool to assess the condition of crops and as an aid to management decisions.
- Learn how to sample root systems, measure CHO content and operate the ***AspireUK*** website (www.aspireuk.org).

- Monitor plant populations, especially in establishing crops, to identify ones that are losing plants and therefore capacity to accumulate CHO; plant losses often result from excessive depletion of root CHO caused by high harvesting pressure.

2 SCIENCE SECTION

2.1 Introduction

AspireNZ is an internet-based interactive decision support system (DSS) designed to help growers achieve high asparagus yields through better knowledge and management of root CHO dynamics. A detailed description of ***AspireNZ*** is given in a paper that was presented at the 10th International Asparagus Symposium and appended to the year 1 Annual Report (Wilson *et al*., 2002).

The system has five main elements:

- A simple method for assessing the CHO status of roots.
- Information about interpreting the CHO values and using them to help make crop management decisions. The system does not make decisions – it interprets information about crops and suggests options to help users reach the best decisions.
- An interactive delivery system that is deployed on the internet (www.aspirenz.com).
- A database which retains information about each crop registered with the system. This information can be retrieved at any time so that users can retrospectively evaluate the effects on crop performance of previous management decisions.
- Secure user and crop registration. Each subscriber can register and operate the system for several crops, and their information is protected by a secure username and password system.

The aim of this project was to develop and deploy ***AspireUK***, a version of the ***Aspire*** system tailored for UK environmental and production conditions.

The project had five main stages:

- At the start of the project, the ***AspireUS*** version of the system was deployed on the internet as an ***AspireUK*** prototype for use by project personnel.
- A crop sampling programme was conducted for two years to:
  - determine whether crops in the UK have patterns of CHO content and 'ideal' root CHO contents that are the same as those found in crops in New Zealand.
  - Define the CHO patterns of UK crops if they are different from crops in New Zealand.
  - Identify crops with deviations from the normal CHO pattern, identify the causes, and determine how they are associated with above-ground growth irregularities.
- Based on the collated data and grower feedback, determination of how CHO deviations can be interpreted to help diagnose and resolve problems in UK crops.
- Progressive adaptation of technical information in the system during the project to create ***AspireUK.***
- Completion of the decision support system ready for commercial deployment in the UK.

This Final Report provides a summary of data obtained from both project years and interpretation of root CHO dynamics in relation to spear yield, fern growth and root biomass. Use of the data to modify and finalise the ***AspireUK*** system is described.

2.2 Methods

2.2.1 AspireUK on the internet

At the start of the project, New Zealand Institute for Crop & Food Research (NZICFR) made available a prototype of ***AspireUK***, which was the same as ***AspireUS***, on the internet at www.aspireuk.org. Project participants including collaborating growers were given a Username and Password to allow access for web-site testing and familiarisation during the project. Training in use of the system was provided at a project start-up meeting in March 2005.

2.2.2 Site selection

Twelve asparagus crops were selected to be monitored over a two-year period, with four crops in each of the main production areas of England (east, south and west). Growers in each region who were interested in participating in the project were each asked to provide details of three of their crops that could potentially be included for monitoring (see Appendix 1 for questionnaire). Crops were selected based on the information provided by growers, with the aim of including three fully established crops (5-10 years old) and one establishing crop (2-4 years old) per region, with a range of yields. It was decided that monitoring would focus on crops of varieties known to perform consistently well in UK conditions (Dutch varieties), but with one crop of a more recently introduced variety (Jersey Giant). The crops that were selected were being managed using similar agronomic practices with the exception of one crop, for which polythene covering was used to promote early harvesting.

2.2.3 Crop sampling programme

Crop monitoring started in March 2005. Prior to this, a project start-up meeting was held in early March 2005 to present the sampling protocols (detailed in a training manual) and train project participants. The protocols were developed by NZICFR, based on techniques used to develop ***AspireNZ*** in New Zealand and to validate the system for the USA. Growers were advised at the meeting that an estimate of spear yield from the crop, preferably separated into marketable and reject components, would be required at the end of harvest. It was also noted that 12 plants (crowns and roots) would need to be removed from each site for root biomass measurements in autumn 2005, and that assistance with sample digging would be gratefully received. The crop sampling schedule for the duration of the project was planned as shown in Table 2.1.

Table 2.1. Sampling times and measurements during the ***AspireUK*** project

Sampling Time	Measurement					
	Root CHO		Fern Biomass		Root Biomass	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Dormancy, Pre-Harvest	✓	✓				
End of Spear Harvest	✓	✓				
End of Fern Establishment	✓	✓	✓	✓		
Peak of Fern Growth	✓	✓	✓	✓		
Dormancy, End of Autumn	✓	✓			✓	

2.2.3.1 Dormancy, pre-harvest

The selected crops were sampled in March 2005, before dormancy had broken and before the first spears started to emerge. Within each selected crop, an area of approximately 1 ha (for crops larger than this area) was designated for subsequent sampling activities, ensuring that this area contained a single variety, and trying to avoid atypical soil conditions.

Root samples from 20 random positions in the field were collected, labelled and stored in a cool box following the standard sampling protocol (Appendix 2). Features of root growth and health were noted as well as observations on crop management (by the assessor and the grower if present). In the laboratory, the root samples were processed and the Brix% of their sap solution measured following the standard sampling protocol (Appendix 2) and the data were recorded. The Brix% scale provides a measure of the sugar content of a solution at a given temperature and can be measured using a refractrometer. Use of Brix% readings for determining asparagus root CHO content is described in Section 2.2.4 and in Wilson *et al*., 2002.

This procedure was repeated using the same selected crop area of each of the twelve fields in February and March 2006.

2.2.3.2 End of spear harvest

In both 2005 and 2006, the selected crops were sampled within two to three days before or after the end of harvest, before spears had started to elongate and grow into ferns.

Root samples from 20 random positions in the field were collected, labelled and stored in a cool box following the standard sampling protocol (Appendix 2). Features of root growth and health were noted as well as observations on crop management (by the assessor and the grower if present). In the laboratory, the root samples were processed and the Brix% of their sap solution measured following the standard sampling protocol (Appendix 2) and the data were recorded.

Between the end of spear harvest and fern establishment in 2005, areas with representative soil conditions suitable for future fern and root biomass sampling were identified. Six areas in each crop, each four rows wide

and 10 m long, were marked (plastic markers in each end of row 1, markers at the field edge, and location map). Rows and plants within the six areas were then allocated for sampling on successive occasions, as follows:

Row 1: Fern growth at the end of fern establishment in year 1 (2005)
Row 2: Fern growth at the peak of fern growth in year 1 (2005)
Pair of plants at one end of the area: Root biomass in December 2005/January 2006
Row 3: Fern growth at the end of fern establishment in year 2 (2006)
Row 4: Fern growth at the peak of fern growth in year 2 (2006).

2.2.3.3 End of fern establishment

In both 2005 and 2006, the crops were sampled in July, about one month after the end of spear harvest. At this stage, ferns had established fully, "feathered" out and no more stems were emerging. Root samples from 20 random positions in the field were collected, labelled and stored in a cool box following the standard sampling protocol (Appendix 2). Features of root growth and health were noted as well as observations on crop management (by the assessor and the grower if present). In the laboratory, the root samples were processed and the Brix% of their sap solution measured following the standard sampling protocol (Appendix 2) and the data were recorded.

Fern growth was measured as follows: The numbers of small, medium and large ferns in a 10 m row of each of the six sampling areas were counted (row 1 in 2005, row 3 in 2006). Ten representative small, medium and large ferns (i.e. a total of 30 ferns) from each of the measured rows were cut and the fresh weight of each group of 10 ferns was measured. A representative combined sub-sample of the ferns was retained. After measuring fresh weight, the sub-samples were dried to a constant weight in a drying oven (100^{o}C/48 h), prior to dry weight measurement and calculation of percentage dry matter content.

2.2.3.4 Peak of fern growth

In both 2005 and 2006, crops were sampled in August, when the fern was fully active and prior to senescence (approximately one month after end of fern establishment).

Root sampling and processing was done as described in Section 2.2.3.3 except that sampling from areas where fern had previously been cut was avoided. The same tasks were completed as at the end of fern establishment for fern biomass (Section 2.2.3.3), except the fern growth measurements were taken from row 2 of each sample area in 2005 and from row 4 in 2006. In addition to counting the ferns in each of the six 10 m lengths of row, the number of missing plants within each 10 m row was recorded. In 2005, the two plants were identified at the end of each sampling area (twelve in total) to be excavated at the end of autumn for measuring root biomass, by selecting representative plants with typical fern growth.

2.2.3.5 Dormancy, end of autumn

Crops were sampled in December 2005/January 2006 and again in November/December 2006, when fern had senesced fully. Root samples were collected and processed as described previously (Section 2.2.3.3) except that sampling from areas where fern had previously been cut was avoided. In December 2005/January 2006, root biomass was measured as follows: the six pairs of representative plants, chosen at the previous sampling time, and all their associated roots were excavated from an area defined as shown in Figure 2.1. The roots and crowns were washed to remove soil, and excess water allowed to dry-off. The dead/hollow roots were separated from healthy roots and crown material. The total fresh weight of dead roots and the total fresh weight of healthy roots were recorded. For both the dead root material and the healthy root/crown material, a combined sample was retained to fit in an oven tray. The fresh weight of the dead root representative sample and the fresh weight of the healthy root representative sample were recorded. The dead and healthy root representative samples were dried to a constant weight in a drying oven (100^{o}C/48 h), dry weights measured, and the results were used to calculate the dry matter content of each root type.

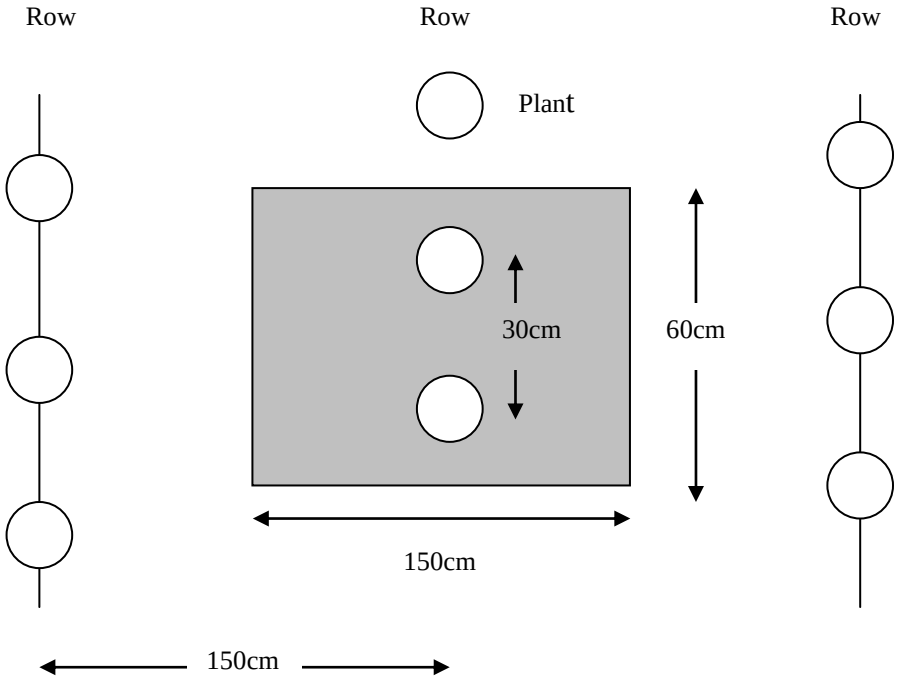

Figure 2.1. Diagram of area excavated (shaded) around pairs of sample plants at the dormancy (end of autumn) sampling occasion.

2.2.3.6 Crop performance questionnaire

A questionnaire was sent out to participating growers in autumn 2005 and 2006 (Appendix 3) to obtain information on yield, harvest dates and other relevant cropping information (e.g. pest and disease issues).

2.2.4 Data handling

The 20 Brix% readings from each sampling occasion were converted to equivalent root CHO contents on a dry weight basis using the linear regression equation from ***AspireNZ*** and ***AspireUS*** (Wilson *et al.,* 2002). An initial mean of the 20 values was calculated, then the final mean CHO content was calculated after discarding any values that were more than two standard deviations away from the initial mean. This procedure for obtaining a reliable estimate of mean CHO content, and the need for at least 20 root samples on each sampling occasion, was developed to account statistically for the fact that there is substantial variation among plants within most asparagus crops.

Fern biomass was estimated from the counts and dry weights of small, medium and large ferns in the six 10 m lengths of row measured in each crop. The biomass of fern in each size class was calculated, then they were aggregated and, finally, the total was scaled up to kg/ha by assuming that there were 6667 m of row length per ha (i.e. rows were 1.5 m apart).

Biomass values of healthy and dead roots were calculated by scaling up the measurements made on two plants per plot to kg/ha using the plant populations that were counted at the peak of fern growth. In some cases, these populations were considerably lower than the original established population.

The weight of CHO in the root system at the end of autumn was calculated as the product of healthy root biomass and the CHO content. The rest of the root weight was taken to be structural biomass, and this was assumed to be a stable quantity during the year. On the basis of this assumption, backward calculations were done to estimate the weight of CHO in the root system at each time of root sampling during the year.

2.2.5 Developing AspireUK

Following completion of data collection, four tasks were required to adapt the prototype ***Aspire*** system for UK climate and production conditions, and to have it ready for commercial deployment to the UK asparagus industry:

1. Edit generic information and methodology pages in both the public and private domains of the existing ***Aspire*** website.
2. Identify the benchmark bands of CHO values to incorporate in the system, for each stage of the annual growth cycle. This was done by considering the CHO patterns measured in the monitored crops, and by identifying the 'ideal pattern' and interpreting deviations from the ideal.
3. Write the library of "Comments and Recommendations" that will appear as scenarios on ***Aspire*UK** in response to the diverse CHO values that occur at different times. Deviations from ideal patterns caused by identified agronomic and environmental factors made it possible to develop scenarios with practical recommendations for growers.
4. Update software codes, upload material and structure the crop database onto the live ***AspireUK*** website.

2.3 Results and discussion

2.3.1 Site details

The characteristics of the sites selected for monitoring during the project are summarised in Table 2.2. Four of the sites (E2, E4, S4 and W1) were categorised as young crops, planted in 2002 or later, with a first full harvest planned for 2005. The others were classed as established crops, having previously had at least one full harvest. Dutch varieties are being grown at all of the sites except E4 where an American variety, Jersey Giant, is grown. The sites include a range of soil types, with the lightest soil being at E4, and field sizes range from 0.6 ha to 37.0 ha. Planting material types included crowns and transplants. The previous performance of the crops was contrasting, with S1, W2 and W3 having low gross yields in 2004 (2.5 t/ha or less) compared with high yields for E2 (despite a short harvest season), S2 and W4 (4.2 t/ha or more). Previous fern vigour also varied with site. Growers noted various production constraints including phytophthora root rot (S1, S2 and E1) and stemphylium purple spot (e.g. W4). Polythene covers to promote early harvesting were being used on crop W1.

2.3.2 Sampling programme

Sampling dates at the different stages of crop development during project year 2 are shown in Table 2.3. Project year 1 sampling dates are shown in the year 1 annual report. In 2005, the end of harvest sampling dates were within +/- 4 days from when the grower stopped harvest, except for S1 (+ 9 days) where the grower closed earlier than expected. In 2006, the end of harvest sampling dates were within a week of the end of harvest, except for two sites W1 and W3 when the growers stopped earlier than expected. In both years, end of fern establishment sampling (mid-late July) took place approximately one month after the end of harvest, and peak fern growth sampling approximately one month later (mid-late August). In 2005, dormancy sampling commenced in December and continued in January, since fern senescence was delayed due to unusually mild autumn weather. In 2006, dormancy sampling commenced in November and was completed in December.

Table 2.2. Characteristics of sites selected for monitoring over a two year period

Site	Area (ha)	Soil-type	Year planted	Category*	Population at planting (plants/ha)	Variety	Planting material	No. days harvest in 2004	Gross yield (t/ha) in 2004	Fern growth in 2004	Other issues
E1	6.0	Silty loam	1997	Established	21,500	Geynlim	Crowns	55	4.0	Average	Phytophthora rot and poor drainage
E2	2.7	Sandy silt loam	2002	Young	21,500	Geynlim	Crowns	45	4.9	Excellent	None
E3	15.0	Sandy clay loam	2000	Established	24,000	Geynlim	Transplants	51	1.7 (net/tips)	Excellent	Waterlogging (in places)
E4	37.0	Loamy sand	2002	Young	25,000	Jersey Giant	Crowns	43	Data not available	Average	-
S1	5.0	Sandy loam	1998	Established	20,000	Geynlim	Transplants	60	2.5	Average	Phytophthora rot in 2003
S2	3.0	Sandy loam	1996	Established	22,250	Venlim	Transplants	60	4.2	Good	Phytophthora rot
S3	1.8	Sandy loam	1998	Established	21,700	Geynlim	Transplants	58	3.8	Average	Slight asparagus beetle
S4	0.6	Sandy loam	2002	Young	22,500	Geynlim	Crowns	Data not available	Data not available	Excellent	Asparagus beetle. Rubble in crop
W1	9.3	Sandy loam	2003	Young	24,000	Geynlim	Crowns	50	3.3	Good	Polythene covered; Stemphylium purple spot and asparagus beetle
W2	1.2	Sandy loam	1999	Established	20,000	Geynlim	Transplants	55	1.2	Poor	Small spears
W3	1.8	Sandy loam	1999	Established	25,000	Geynlim	Transplants	55	2.3	Poor	Asparagus beetle; very thin spears in 2004
W4	3.2	Sandy loam	2001	Established	22,200	Backlim	Transplants	57	4.5	Average	Stemphylium purple spot – high in Sept 2004; Weeds during establishment

*Established - at least one full harvest taken prior to 2005; Young - first full harvest taken in 2005.

Table 2.3. Sampling dates at different stages of crop development (2005-2006).

Region	Site code	Pre-harvest sampling	End of harvest sampling	End of fern establishment sampling	Peak fern growth sampling	Dormancy Sampling
East	E1	28/02/06	24/06/06	21/07/06	18/08/06	20/11/06
	E2	23/02/06	23/06/06	24/07/06	30/08/06	17/11/06
	E3	20/03/06	22/06/06	28/07/06	25/08/06	09/01/07
	E4	17/03/06	15/06/06	18/07/06	15/08/06	19/12/06
South	S1	08/03/06	26/06/06	26/07/06	22/08/06	28/11/06
	S2	08/03/06	26/06/06	26/07/06	23/08/06	28/11/06
	S3	07/03/06	21/06/06	19/07/06	16/08/06	29/11/06
	S4	07/03/06	20/06/06	20/07/06	17/08/06	29/11/06
West	W1	14/03/06	28/06/06	19/07/06	31/08/06	06/12/06
	W2	15/03/06	28/06/06	26/07/06	31/08/06	05/12/06
	W3	15/03/06	21/06/06	21/07/06	19/08/06	05/12/06
	W4	21/03/06	27/06/06	25/07/06	24/08/06	08/11/06

2.3.3 Key crop performance indicators

The state and performance of the 12 crops varied widely. By 2006 their ages since planting were from three to 10 years, so they ranged from young, establishing crops to established, mature ones. This section presents information about the below-ground state of the crops, which is seldom available for asparagus, as well as the more familiar indicators of above-ground performance.

The size of each crop's root system was measured at the end of 2005. These results, combined with other measurements, were used to determine key below-ground indicators of the state of each crop as it approached winter dormancy at the end of the fern growth period in 2005 and 2006. These indicators are shown in Table 2.4.

A crop's root system size is determined by the product of average size per plant and the number of plants per hectare. The roots of each plant consist of two main components: the root structure, which changes slowly with time, and the CHO contained within the structure, which fluctuates over a large range during the year. At the end of 2005, the average structural dry weight varied over a three-fold range among the 12 crops, from 0.18 to 0.55 kg per plant (Table 2.4). Plant population varied from about 17,000 to 24,000 plants per hectare, with crops having lost from 0 to 27% of their plants since establishment. As a result, structural dry weights of the root systems ranged from about 3.7 to 11.7 t/ha. Most root systems were full at the end of the season so CHO weights spanned a similar range, from 3.2 to 14.3 t/ha. Total root system dry weights (structure plus CHO) ranged from 7.6 to 26.0 t/ha.

By the end of 2006, the range of root system sizes again varied by more than three-fold. Most of the weights were lower because further plants had been lost from most of the crops. In some cases large losses had occurred, with from 6 to 43% lost since establishment. As a result, populations ranged from about 11,400 to 21,100 plants per hectare, and structural dry weights varied from about 3.4 to 10.5 t/ha. CHO and total weights ranged from 3.2 to 14.8 t/ha and 7.3 to 25.3 t/ha respectively.

Spear and fern growth, the main above-ground indicators of crop performance, for the 12 crops during 2005 and 2006 are shown in Table 2.5. In contrast with other data, spear yield data were not collected using standard methodology. They were provided by the collaborating growers who had differing systems of yield recording and as a result, there is some uncertainty in comparisons of yield data.

In both years spear yields ranged from about 2,000 to over 6,000 kg/ha. These yields were produced over harvest periods from 46 to 59 days. A notable exception was one crop (W1), which produced 6,600 kg/ha over an 89 day harvest period in 2005. The average rate of spear yield production during harvest, which is driven mainly by temperature and the availability of CHO for spear growth, differed three-fold among the 12 crops with a range from about 40 to 120 kg/ha/day.

The average spear yield of individual plants during harvest ranged from about 0.1 to 0.3 kg. This meant that each plant produced from 5 to 15 spears during the harvest period, assuming an average weight of 20 g per spear.

Values of the ratio of spear yield produced and the amount of CHO available in the storage root system (from Table 2.4) ranged from 0.3 to 1.6. High values indicated that crops converted available CHO to spear yield efficiently while low values showed inefficient utilisation of CHO. Low values indicated unrealised yield opportunity, and high yielding crops were not necessarily the most efficient.

Fern growth was generally greater in 2005 than in 2006, perhaps because of dry conditions during the fern establishment period in 2006. In 2005 it ranged from about 1,500 to 5,900 kg/ha and in 2006 the range was about 1,100 to 5,100 kg/ha. Good, but not excessive, fern growth is needed to fully recharge root CHO content, and inadequate fern growth was unlikely to have limited recharge in most of the 12 crops.

Table 2.4. Key below-ground features and performance indicators of the 12 crops approaching dormancy (end 2005 and 2006)

Site	Planted Population (plants/m^2)	Crop Age in 2006 (years)	Root Structure (kg/plant)	2005					2006				
				Population (plants/m^2)	Plants Lost (%)	Structure (t/ha)	CHO (t/ha)	Total Root (t/ha)	Population (plants/m^2)	Plants Lost (%)	Root Structure (t/ha)	CHO (t/ha)	Total Root (t/ha)
E1	21,500	9	0.51	21,070	2	10.73	9.71	21.44	18,300	15	9.32	7.75	17.07
E2	21,500	4*	0.40*	21,070	2	8.48	11.10	19.58	19,780	8	7.93*	9.70	17.63
E3	24,000	6	0.24	19,920	17	4.69	5.27	9.96	19,200	20	4.62	6.44	11.06
E4	25,000	4*	0.18*	21,000	16	3.74	3.84	7.58	21,000	16	3.88*	3.48	7.36
S1	20,000	8	0.28	17,600	12	4.93	3.20	8.13	17,600	12	4.93	3.20	8.13
S2	22,500	10	0.37	17,130	27	6.32	5.36	11.68	15,100	32	5.44	4.34	9.78
S3	21,700	8	0.55	19,310	11	10.62	10.50	21.12	17,900	17	9.62	10.47	20.09
S4	22,500	4*	0.39*	21,150	6	8.20	7.15	15.35	21,150	6	8.20*	8.70	16.90
W1	24,000	3*	0.21*	24,000	0	5.03	5.25	10.28	19,440	19	4.14*	3.19	7.33
W2	20,000	7	0.32	18,800	6	5.94	5.80	11.74	11,400	43	3.55	6.51	10.06
W3	25,000	7	0.24	24,000	4	5.84	5.30	11.14	14,000	40	3.40	4.51	8.91
W4	22,200	5	0.53	22,200	0	11.69	14.34	26.03	19,800	11	10.45	14.85	25.30
Mean	22,492	6	0.35	20,600	9	7.18	7.24	14.50	17,890	20	6.42	6.93	13.30
Max	25,000	10	0.55	24,000	27	11.69	14.34	26.03	21,150	43	10.45	14.85	25.30
Min	20,000	3	0.18	17,130	0	3.74	3.20	7.58	11,400	6	3.40	3.19	7.33

* Young establishing crops with root systems still expanding

Table 2.5. Key above-ground features and performance indicators of the 12 crops (2005 and 2006)

Site	2005							2006						
	Spear Yield (kg/ha)	Harvest Length (days)	Yield per Day (kg/ha)	Yield per Plant (kg)	Spears per plant	Spear Yield/ Root CHO	Fern Growth (kg/ha)	Spear Yield (kg/ha)	Harvest Length (days)	Yield per Day (kg/ha)	Yield per Plant (kg)	Spears per plant*	Spear Yield/ Root CHO	Fern Growth (kg/ha)
E1	3,000	53	57	0.142	7	0.31	4,100	3,500	51	69	0.191	10	0.45	3,010
E2	5,400	53	102	0.256	12	0.49	4,730	6,200	51	122	0.313	15	0.64	5,140
E3	3,000	52	58	0.151	8	0.57	4,040	3,000	49	61	0.156	8	0.47	3,730
E4	3,000	-	-	0.143	7	0.78	2,870	1,800	49	37	0.086	4	0.52	1,970
S1	2,100	48	44	0.119	6	0.66	5,910	3,100	59	53	0.176	8	0.97	3,000
S2	5,300	56	95	0.309	15	0.99	5,710	4,700	52	90	0.311	15	1.08	3,940
S3	3,600	57	63	0.186	9	0.34	2,820	3,200	47	68	0.179	9	0.31	1,400
S4	4,400	56	78	0.208	10	0.62	3,170	4,400	49	90	0.208	10	0.51	3,020
W1	6,600	89	74	0.275	14	1.26	1,490	5,000	63	79	0.257	13	1.57	4,720
W2	2,800	59	47	0.149	7	0.48	2,830	1,200**	58	21**	0.105	10**	0.37**	2,020
W3	2,400	58	41	0.100	5	0.45	2,080	1,800	45***	40	0.128	6	0.40	1,120
W4	5,100	57	89	0.230	11	0.36	4,360	4,400	46	96	0.222	11	0.28	4,190
Mean	3,890	58	68	0.189	9	0.61	3,680	3,593	51	73	0.194	10	0.65	3,105
Max	6,600	89	102	0.309	15	1.26	5,910	6,200	63	122	0.313	15	1.57	5,140
Min	2,100	48	41	0.100	5	0.31	1,490	1,800	46	37	0.086	4	0.28	1,120

*Assuming an average weight of 20 g per spear (10 g for W2) ** Tips only harvested *** Uncertain end of harvest date

2.3.4 Root carbohydrates

Root CHO contents are presented in tabular form (Table 2.6) and also in graphical form (Figure 2.2), to demonstrate depletion and accumulation during the year.

The root CHO content for almost all of the test crops followed the expected pattern of depletions and accumulation as demonstrated from previous work in New Zealand and the USA. In general, CHO content was always high at the start of harvest, declined during harvest, declined further to a minimum level during fern establishment, and then recovered again during fern growth to reach a high level by the end of autumn. Most crops deviated from the 'ideal' pattern in some way and there was much variation in the root CHO values at various times during the cycle. There were many possible reasons for the variation that depended on the circumstances of each crop, but the reasons can be separated into two general categories:

- Differences associated with the size of the root system. Root biomass varies widely among crops. The size of the system determines the capacity of a crop to accumulate and store CHO, and therefore it influences the extent of CHO fluctuations during the annual cycle. In general, crops with small root systems (i.e. small CHO storage capacity) exhibit larger CHO content fluctuations than crops with big root systems, even though the quantity of stored CHO maybe considerably greater in the latter. The impact of root system size is evaluated for each of the crops in Section 2.3.5.
- Difference attributable to particular agronomic conditions in individual crops. Many differences are caused by effects of management and environmental factors that can be identified readily. Examples are reduced CHO accumulation caused by the effects of an unfavourable growing season, low fern vigour, and weed, pest and disease problems during fern growth. These factors are evaluated for each of the crops in Section 2.3.5.

Table 2.6. Root CHO content values for 12 asparagus crops monitored at five stages of crop growth in over two years (2005 and 2006)

Site	Root CHO content (mg/g) at different crop growth stages									
	Dormancy (pre-harvest)		End harvest (End of June)		End of fern establishment		Peak fern growth		Dormancy (end of season)	
	2005	2006	2005	2006	2005	2006	2005	2006	2005/6	2006
East 1	475	454	327	327	250	258	393	500	477	443
East 2	567	550	355	321	203	293	407	391	530	512
East 3	529	582	320	400	223	339	459	507	625	588
East 4	507	473	357	388	253	371	335	428	464	608
South 1	394	395	278	286	242	251	367	436	434	556
South 2	459	444	303	312	300	291	408	559	513	547
South 3	497	521	354	335	302	269	398	464	490	485
South 4	472	509	346	338	255	236	516	491	506	530
West 1	511	435	295	277	281	334	391	530	457	575
West 2	494	647	341	379	271	307	459	559	614	543
West 3	476	547	287	*	289	280	426	463	496	652
West 4	551	587	365	475	285	281	460	488	554	549
Mean	494	512	327	349	263	292	418	485	513	549

*Missing value as sampling time did not coincide with end of harvest

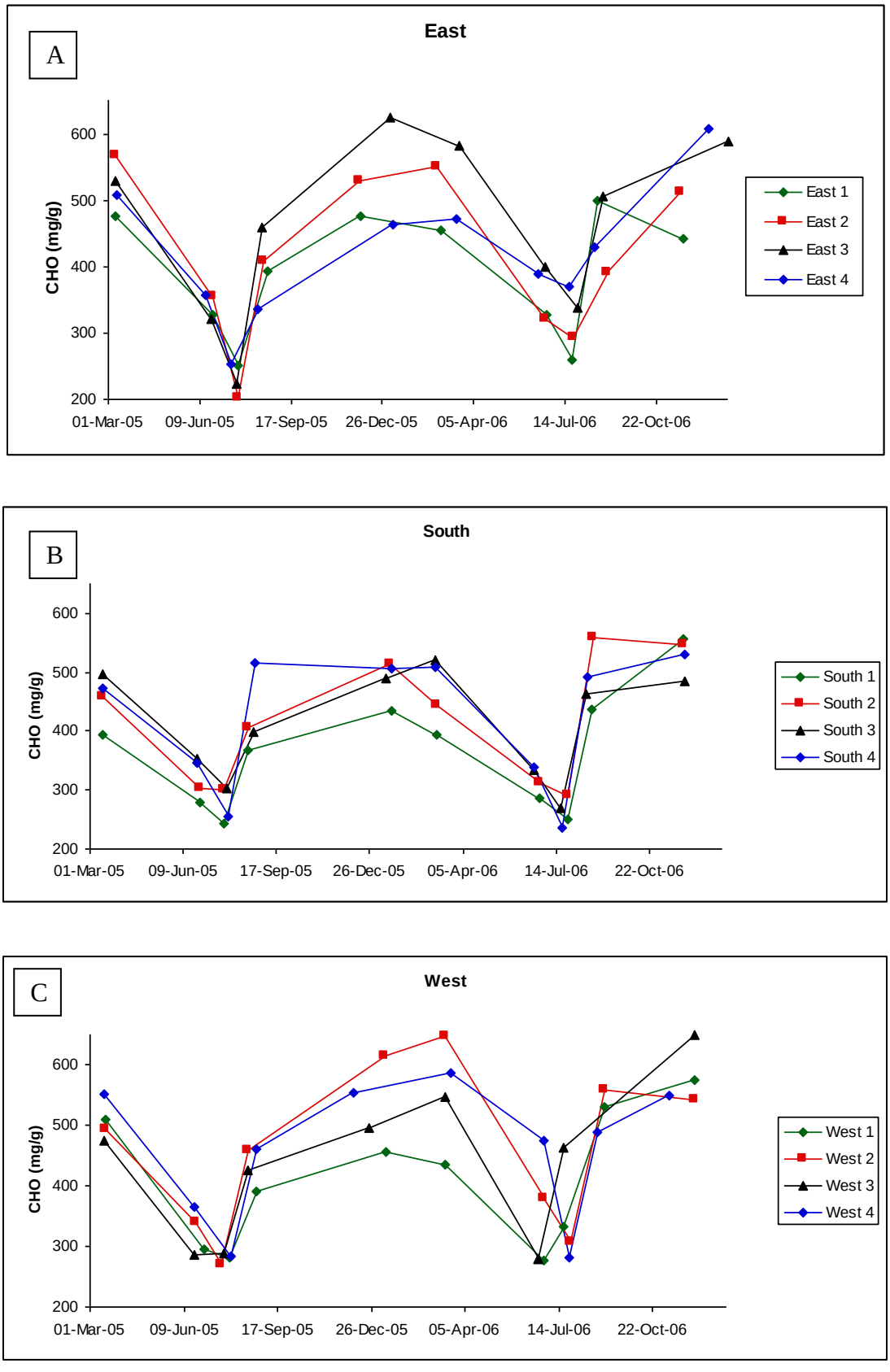

Figure 2.2. Root CHO content values for 12 asparagus crops sampled at five stages of crop growth in 2005 and 2006, in three regions, east (A), south (B) and west (C)

2.3.5 Crop profiles

The 12 crops have been grouped according to yield performance, and are discussed individually below, using information from the key crop performance indicators (Tables 2.4 and 2.5), root CHO dynamics (Table 2.6 and Figure 2.2), and summary crop profiles (Appendix 4).

2.3.5.1 High yielding crops

E2: A young, healthy vigorous crop that was one of the highest yielding in both sampling years. The root biomass was large for a young crop indicating excellent establishment and vigour, and as a result, plant loss has been low to date. It also had good fern growth in both years. It showed a close to ideal pattern of CHO accumulation and depletion, commencing at 550 mg/g CHO or more pre-harvest in both seasons. After the first full harvest in 2005 (53 days), CHO levels dropped to around 200 mg/g by the end of fern establishment, which is normal for a young crop at this stage in the season. CHO recharge was satisfactory and exceeded 500 mg/g by dormancy. A similar pattern was observed in 2006 with a higher yield taken during a 51-day harvest period.

S2: The oldest field with a moderate root system size. A history of phytophthora root rot (now treated annually with metalaxyl-M) has resulted in about 30% plant loss and variable root health. Nevertheless, fern growth and spear yield have been good in both seasons. The crop had a good pattern of CHO accumulation and depletion in both years, except for two deviations. Firstly, there was a substantial reduction of CHO content during the 2005/2006 winter. Possible reasons for this are root damage due to phytophthora rot or the effects of cultivations. Secondly, root CHO content was fully recharged earlier than usual during fern growth in 2006, due possibly to favourable environmental conditions and because it had a relatively small root system.

W1: A young crop that was one of the highest yielding in both sampling years. It has been harvested intensively during its early years and as a result, the root biomass is small because individual plants have not expanded their root systems and already 20% of plants have been lost by year 3. Harvests started early in both years through use of polythene covers and were extended beyond the normal end of harvest date in 2005 (89 days). Following the extended harvest, fern growth was poor and as a result, CHO accumulation by dormancy was well below optimum (457 mg/g) for a small root system. A shorter harvest (63 days) allowed the opportunity for greater CHO recharge and crop recovery during fern growth in 2006. The crop will need careful management if high yields are to be sustained.

W4: An established, vigorous crop with the largest root system and strong fern growth. It had few pest and disease constraints and minimal plant loss. Despite these positive features, yields were good but not exceptional. The crop showed a close to ideal pattern of CHO accumulation and depletion, except that values were much higher than they needed to be at the end of harvest (365 and 475 mg/g in 2005 and 2006, respectively) based on

AspireUK benchmarks (see Section 2.3.6). These high values, combined with the fact that the harvest durations were only about 50 days, suggest a missed opportunity for higher yields. Harvests could have been extended with little risk of adversely affecting CHO recovery and crop health.

2.3.5.2 Moderate yielding crops

E1: An older established crop with one of the larger root systems, but with declining vigour and accelerating loss of plants due in part to phytophthora rot and weed competition. Despite the large root system, the crop had variable fern growth and produced only moderate spear yields in both years. It had a close to ideal pattern of CHO accumulation and depletion but pre-harvest CHO levels were lower than desirable in both years (<500 mg/g). There was a sharp decline in CHO content towards the end of fern growth in 2006, perhaps caused by late flushes of fern growth possibly stimulated by heavy August rainfall.

E3: An established crop but with a small root biomass because individual plants have not expanded their root systems and 20% of plants have been lost. A likely cause is the combination of heavy soil, waterlogging and root damage due to phytophthora. Fern growth was strong and spear yield moderate in both years. Peak CHO contents were high (about 600 mg/g), a common feature of crops with small root system capacities that often exhibit larger CHO content fluctuations.

S1: An established crop with one of the smallest root biomass values because of small individual plant size and relatively low plant population. Despite strong fern growth, spear yields have been low to moderate and CHO recharge has been poor. The pattern of CHO accumulation and depletion has been good, but values have been consistently low with pre-harvest CHO values less than 400 mg/g in both seasons despite the small root system capacity. A high CHO value at the end of 2006 suggests some crop recovery.

S3: An established crop with one of the largest root biomass values. It has large individual plant size and good plant population. The pattern and levels of CHO content have been good. Despite these positive features, crop performance has been poor. Fern growth has been patchy in both years, with one of the lowest biomass values in 2006. This has resulted from poor root health and the effects of weeds, pests and foliar diseases. Consequently, spear yields have been moderate.

S4: An establishing vigorous crop with a high root biomass and few plants lost. Spear yield (estimated) and fern growth were good in both years. The pattern of CHO accumulation and depletion was good in both seasons. A notable deviation was that, following rapid CHO recharge during early fern growth, accumulation stopped prematurely in both years due to the effects of severe stemphylium outbreaks in late summer/autumn (plus secondary fern flushes in 2006).

2.3.5.3 Lo

E4: A young
size of all the
subsequent c

CHO dynamics followed the usual pattern but the amplitude of gains and losses was less than expected for a crop with such a small root system. A high CHO value at the end of 2006 (608 mg/g) suggests some crop recovery.

W2: A mature crop that has reportedly struggled since establishment and is now in classical decline. It has average root biomass, which is decreasing as plants are lost (43% lost by 2006). Fern growth was below average with damage caused by beetle and stemphylium in both years. Low yields were characterised by thin spears with 75% less than 10 mm diameter. The CHO content followed the usual pattern, with a large range reflecting the small size of the root system. A CHO value of 647 mg/g in March 2006 was the highest pre-harvest value recorded in all the crops. Root CHO content reached a maximum early in fern growth in 2006, then declined possibly due to the damaging effects of stemphylium and beetle.

W3: A mature crop that has reportedly struggled since establishment and is now in classical decline. It has average root biomass, which is decreasing as plants are lost (40% lost by 2006). Fern biomass and spear yields were very low in both years. CHO dynamics followed the usual pattern but the amplitude of gains and losses was less than expected for a crop with such a small root system. A very high CHO value at the end of 2006 (652 mg/g) following a short harvest suggests some crop recovery.

2.3.6 Developing AspireUK

For each growth stage, the CHO values recorded in the monitored crops (Table 2.6) were separated into bands from high to low, with each band spanning a 100 mg/g range. This allowed identification of where the 'ideal' values should be for each growth stage. It also allowed outliers to be identified. The bands thus obtained were considered in the light of previous experience in New Zealand and North America. From these we derived the optimum range of CHO values for each growth stage in UK conditions. In general, the ranges were similar to those determined in other countries. The main exception was that the maximum CHO values achieved both at dormancy and pre-harvest were generally higher in UK crops.

An example of the procedure is illustrated in Table 2.7. In this case, CHO values ranged from about 390 to 650 mg/g, with most crops between 450 and 550 mg/g. There were identifiable agronomic reasons for values outside this range, and these outliers helped with the development of interpretations that were incorporated in the comments and recommendations that were created for ***AspireUK*.**

Table 2.7. Fields in each four CHO bands proposed for pre-harvest recommendations in ***AspireUK***

CHO band (mg/g)	Year 1	Year 2	Summary (and example recommendation)
<350	Nil	Nil	Extremely low (nil harvest?)
350-450	S1,	S1, S2, W1	Low (reduced harvest?)
450-550	E1, E3, E4, S2, S3, S4, W1, W2, W3	E1, E2, E4, S3, S4, W3	Ideal (Normal harvest?)
>550	E2, W4	E3, W2, W4	High (Extended harvest?)

In summary, benchmark CHO values were as follows:

- In general, the target 'full' root CHO content at dormancy and pre-harvest should exceed 550 mg/g. This target is higher than the values in New Zealand and the US.
- Target end of harvest CHO content is within a range of 250-350 mg/g with an ideal end point of about 320 mg/g. This is slightly higher than was set for New Zealand and the US. The higher target in ***AspireUK*** reduces the likelihood of growers prolonging harvest duration too much in the limited UK growing season length.
- The normal range for the end of fern establishment is 200 to 300 mg/g ('empty' root system). It is a less important decision benchmark, but experience in New Zealand and the US is that depletion below 200 mg/g should be avoided.

These CHO values need to be interpreted in relation to each crop, especially taking account of the size of the functional root system. ***AspireUK*** provides interpretations for three general classes of root systems: i) young establishing crops with small but expanding systems, ii) older crops with declining systems, indicated by a high proportion of dead roots and, iii) older crops with large root systems. ***AspireUK*** also provides interpretations of deviations from the target values and gives general recommendations to help growers identify potential management remedies to correct the causes of the deviations.

In some circumstances ***AspireUK*** suggests that an extended harvest might be possible without harming the crop. This recommendation is given with a proviso that it is important to achieve a balance between CHO targets and the timing of crop development. For example, following a recommendation to continue harvesting beyond the normal end-date should be done in the knowledge that it could affect the prospect of full CHO recovery by the autumn.

The finalised website is now available at www.aspireuk.org.

2.4 Overall conclusions

- Root CHO content for most of the 12 British crops followed the expected pattern during the annual growth cycle in both years of testing. This made it possible to readily adapt previous versions of ***Aspire*** for the UK because the results supported the principle that, fundamentally, asparagus crops behave similarly wherever they are grown (Wilson *et al.*, 2007). The main adaptation was to define optimum bands of CHO levels at key times during the crop's growth cycle, specific for UK conditions.

- As expected, there were deviations from the 'ideal' CHO pattern. Identifying the causes and consequences of these deviations aided interpretations to develop recommendations for inclusion in ***AspireUK***.
- Interpretations of root CHO content information depend on the size of the root system. Measurement of root biomass is very difficult and is not included as a feature of ***AspireUK.*** However, growers need a general awareness of root system size in their individual crops to get maximum value from ***AspireUK*** recommendations. ***AspireUK*** provides interpretations for three general classes of root systems: i) young establishing crops with small but expanding systems, ii) older crops with declining systems, indicated by a high proportion of dead roots and, iii) older crops with large root systems.

- In agreement with findings from New Zealand and the US, increasing amounts of fern growth did not necessarily translate into increasing CHO recharge. It was concluded that a large amount of fern is not needed to fully recharge root CHO content. Therefore it is recommended that growers should manage crops to encourage good, but not excessive, fern growth.

- Information from the monitoring programme is now available to growers through the interactive decision support system at www.aspireuk.org.

2.5 References

Wilson, D.R., Cloughley, C.G. & Sinton, S.M. 2002. ***AspireNZ***: A decision support system for managing root carbohydrate in asparagus. *Acta Horticulturae* **589***:* 51-58.

Wilson, D.R., Sinton, S.M., Butler, R.C., Drost, D.T., Paschold, P.J., van Kruistum, G., Poll, J.T.K., Garcin, C., Pertierra, R., Vidal, I. and Green, K.R. 2007. Carbohydrates and yield physiology of asparagus – a global overview. *Acta Horticulturae* (In Press).

2.6 Technology transfer

2.6.1 Year 1

- Project start-up meeting attended by S. Sinton (NZICFR), K.Green (ADAS), J. Carpanini (ADAS), W. Dyer, J. Petchell (Hargreaves Plants) and nine participating growers, at ADAS Arthur Rickwood, March 2005.
- Prototype ***AspireUK*** website (www.aspireuk.org) deployed on the internet, access provided to participants for web-site testing and familiarisation during the project, training in use of the system provided at the start-up meeting, March 2005.
- Project training manual produced by NZICFR distributed to all participants, March 2005.
- Presentation at the AGA agronomy day (March 2005) by V. Aveling and subsequent article in HDC News.
- HDC/AGA Seminar for asparagus growers, with presentations by D. Wilson, S. Sinton and K. Green on 29 June 2005 and subsequent update in HDC News.
- Visits to some growers by S. Sinton, NZICFR (March and June 2005) and D. Wilson, NZICFR (June 2005).
- Brix% readings supplied to participating growers on request.
- 'Validation of ***AspireNZ*** for the UK', presentation by K. Green at the AGA Agronomy Day (March 2006).

2.6.2 Year 2

- '***AspireUK****:* a demonstration workshop for the asparagus industry', 28 March 2007 at PGRO, Cambs.
- 'Aspire shapes up'. Article in 'Commercial Grower', 22 March 2007, p 4.
- Article in April 2007 edition of HDC News (in press).
- Telephone advice to growers interested in subscribing to ***AspireUK.***
- HDC Factsheet on project findings (in prep).
- Brix% readings supplied to participating growers on request.
- ***AspireUK*** website completed for commercial deployment.

2.7 Acknowledgements

The support and cooperation of the British Asparagus Growers Association and individual participating growers during this project is gratefully acknowledged.

3 APPENDIX 1.

Grower questionnaire: potential asparagus crops for *AspireUK* project

1. Site details:

Grower	
Address	
Phone	
Fax	
Email	
Annual rainfall (mm)	
Soil type	

2. Crop details (please provide details on three asparagus crops):

	Crop 1	Crop 2	Crop 3
Variety			
Planting date			
Area planted (ha)			
Crowns or transplants			
Population/ha:			
At planting			
In 2005 (approx.)			
Yield (tonnes/ha) in:			
2001			
2002			
2003			
2004			
No. of days harvest in:			
2001			
2002			
2003			
2004			
Fern growth (Excellent, Average or Poor) in:			
2001			
2002			
2003			
2004			
Polythene covered (yes/no)			
Organic (yes/no)			
Comments on:			
Disease incidence?			
Pests?			

4 APPENDIX 2

Protocol for root sampling and measuring Brix%.

How to Collect Root Samples and Measure Brix%

AspireNZ estimates root system CHO content by assessing measurements of the Brix% of sap solution extracted from storage roots sampled from a crop. Root CHO content is variable within a crop, so at least 20 but not more than 40 root samples are needed on each measurement occasion to obtain a reliable estimate of CHO content.

A. How To Collect Root Samples

Equipment Required:

- Spade.
- 20-40 sealable plastic bags
- Cool box (with ice packs to keep roots cool if the weather is warm)

Procedure:

- Collect samples from 20 random locations in a crop. The locations should accurately represent the whole crop. Avoid seedlings, outside rows and ends of rows.
- Take roots from a typical plant at each sampling location. Use the spade to make a vertical cut about 30 cm deep into the soil, through the roots, just outside the crown area. Then make a second vertical cut, parallel to the first one, about 15-20 cm further away from the crown.
- Lift and remove the roots from between the two cuts. Discard any hollow asparagus roots or roots from other plants such as weeds. About ten 15 cm root pieces are needed for each sample.
- Seal the roots in a plastic bag and store in the cool box.

B. How To Prepare Root Samples For Brix% Measurements

- Keep the 20 samples separate from each other throughout the procedure.
- Remove all soil by washing the roots in cold or lukewarm (not hot) water as soon as possible after collection.
- Drain excess water by laying the roots on paper for a short time.
- Rinse the plastic bag, and then place the roots back in it.
- Freeze the roots in the bags. It is difficult to extract solution from the roots if they are not frozen first. Solution is released when the cell walls break down as the roots thaw.

C. How To Measure Brix%

Equipment required:

- Refractometer (0-32% Brix, temperature-adjusted).
- Distilled water
- 20-40 small plastic beakers
- Robust garlic crusher
- Teaspoon
- Paper towel
- Scissors
- Bucket of clean water

Procedure:

- Take ten root samples from the freezer and lay them out to thaw on paper towel. They need to be thawed completely and free of surface moisture, but do not let them dry out excessively. Pat them dry with paper towel once they are thawed.
- When the first ten samples have thawed, take the next ten out and allow them to thaw while working on the first lot. If all samples are thawed at once some may dehydrate and give an incorrect result.
- Check that the refractometer reads zero with a few drops of distilled water. If not, give it time to reach room temperature (ideally about 20^{o}C). It may be necessary to adjust it to zero (see the refractometer manual).
- Cut the roots into 1-2 cm lengths with scissors.
- Place the pieces in the garlic crusher and squeeze the solution into a plastic beaker.
- Swirl the solution around until it is mixed thoroughly.
- Use the teaspoon to place about three drops onto the prism surface of the refractometer.
- Drop the cover over the juice, avoiding bubble formation.
- Read the Brix% on the refractometer scale and record the result.
- Wipe the prism surface clean with tissues between samples. The refractometer cannot be immersed in water.
- Clean the garlic crusher and plastic beakers thoroughly between samples. Rinse in water and dry carefully. Any water left on the equipment will affect subsequent readings.

5 APPENDIX 3.

***AspireUK*: Crop Performance Questionnaire 2006**

Name:

Field/Crop:

Start of harvest date:

End of harvest date:

Yield t/ha	**Gross**		**Net**		
Spear quality (If information available)	Percentage spears more than 10 mm diameter: Percentage spears less than10 mm diameter: Percentage spears blown & twisted:				
Estimated plant Population per ha	Autumn 2005				
	POOR	AVERAGE	GOOD	EXCELLENT	
Fern Growth					
Diseases/pest issues (Indicate whether nil, slight, moderate or severe)	Phytophthora	Stemphylium	Fusarium	Rust	Beetle
Other Crop Issues					
Further Comments					

Post to:
Jonathan Carpanini, ADAS Arthur Rickwood, Mepal, Ely, Cambs. CB6 2BA

Or fax to:
Jonathan Carpanini, 01354 694488

6 APPENDIX 4.

***AspireUK* Monitoring Project: crop Summaries**

Crop: E1

Region: East
Planted: 1997 **Planted as:** Crowns **Planted Population:** 21,500 plants per ha

	2004	2005	2006
Plants per ha (% lost)		21,070 (2%)	18,300 (15%)
Total Spear Yield (kg/ha)	4,000 (55 days)	3,000 (53 days)	3,500 (51 days)
Spear Yield per Plant (kg)		0.142 (7)	0.191 (10)
Fern Yield (kg/ha)	Average	4,100	3,010
Root Structure (kg/ha) **(0.51 kg/plant)**		10,730	9,320
Root CHO Content (mg/g) **Pre-harvest** **End of Harvest** **Fern Established** **Peak Fern** **End of Season**		 475 327 250 393 477	 454 327 258 ***500*** ***443***
Root CHO (kg/ha) **Pre-harvest**		 9,710	 7,750
Spear Yield/Root CHO		0.31	0.45
Comments	* Phytophthora and poor drainage	* Average fern growth, patches of decline, severe weeds, minor pests and diseases * Woody thin roots, some hollow	* Average fern growth, patches of decline, severe weeds, minor pests and diseases * Woody thin roots, some hollow

Summary: Older crop but holding up well for its age, has a large root system but with declining vigour and appearance consistent with an older crop, main problems are weeds and accelerating loss of plants, CHO pattern looks good except two anomalous results late in 2006.

Crop: E2

Region: East
Planted: 2002 **Planted as:** Crowns **Planted Population:** 21,500 plants per ha

	2004	2005	2006
Plants per ha (% lost)		21,070 (2%)	19,780 (8%)
Total Spear Yield (kg/ha)	4,900 (45 days)	5,400 (53 days)	6,200 (51 days)
Spear Yield per Plant (kg)		0.256 (12)	0.313 (15)
Fern Yield (kg/ha)	Strong	4,730	5,140
Root Structure (kg/ha) **(0.40 kg/plant)**		8,480	***7,930*** (roots still growing)
Root CHO Content (mg/g) **Pre-harvest** **End of Harvest** **Fern Established** **Peak Fern** **End of Season**		 567 355 203 407 530	 550 321 293 391 512
Root CHO (kg/ha) **Pre-harvest**		 11,100	 ***9,695***
Spear Yield/Root CHO		0.49	0.64
Comments	* No problems, heavy soil	* Strong fern growth, minor Stemphylium * Healthy roots	* Even crop, no gaps, strong fern growth but patchy at peak fern, minor Stemphylium * Healthy roots

Summary: Young, healthy, vigorous crop, some plant losses, root system still growing, CHO pattern looks good.

Crop: E3

Region: East
Planted: 2000 **Planted as:** Transplants **Planted Population:** 24,000 plants per ha

	2004	2005	2006
Plants per ha (% lost)		19,920 (17%)	19,200 (20%)
Total Spear Yield (kg/ha)	1,700 (net, 51 d)	3,000 (52 days)	3,000 (49 days)
Spear Yield per Plant (kg)		0.151 (8)	0.156 (8)
Fern Yield (kg/ha)	Strong	4,040	3,730
Root Structure (kg/ha) **(0.24 kg/plant)**		4,690	4,620
Root CHO Content (mg/g) **Pre-harvest** **End of Harvest** **Fern Established** **Peak Fern** **End of Season**		 529 320 223 459 ***625***	 ***582*** ***400*** 339 507 ***588***
Root CHO (kg/ha) **Pre-harvest**		 5,270	 6,440
Spear Yield/Root CHO		0.57	0.47
Comments	* Some water logging, heavy soil	* Average fern growth, patchy waterlogging, some fern die-back in wet areas * Mainly healthy roots, some Phytophthora.	* Vigorous harvest, some weeds * Strong fern growth, missing plants * Thick roots, but lower number

Summary: Established crop, many plants lost, small root systems, spear yields low and not increasing, main cause might be heavy soil and Phytophthora, some recovery with improved drainage, CHO pattern looks good except for elevated peak CHOs because of the small root systems.

Crop: E4

Region: East **Cultivar:** Jersey Giant
Planted: 2002 **Planted as:** Crowns **Planted Population:** 25,000 plants per ha

	2004	2005	2006
Plants per ha (% lost)		21,000 (16%)	21,000 (16%)
Total Spear Yield (kg/ha)	No data (43 days)	3,000 (No data)	1,800 (49 days)
Spear Yield per Plant (kg)		0.143 (7)	0.086 (4)
Fern Yield (kg/ha)	Average	2,870	1,970
Root Structure (kg/ha) **(0.18 kg/plant)**		3,740	***3,880*** (roots still growing)
Root CHO Content (mg/g) **Pre-harvest** **End of Harvest** **Fern Established** **Peak Fern** **End of Season**		 507 357 253 335 464	 473 388 ***371*** 428 ***608***
Root CHO (kg/ha) **Pre-harvest**		 3,840	 ***3,480***
Spear Yield/Root CHO		0.78	0.52
Comments	* Establishing	* Late harvest start, weeds and beetles * Average fern growth, breakage and death, moderate Stemphyllium, late weeds * Many hollow roots, many thinner	* Patchy yield, beetles bad * Weak fern growth, patchy, thin and breaking, thick weeds at peak * Long thin roots

Summary: Establishing, the only Jersey Giant crop, fragile fern growth with many problems, weak small root systems, high early plant loss, spear yield limited by CHO availability, CHO pattern looks OK except for elevated peak CHOs because of the small root systems.

Crop: S1

Region: South
Planted: 1998 **Planted as:** Transplants **Planted Population:** 20,000 plants per ha

	2004	2005	2006
Plants per ha (% lost)		17,600 (12%)	17,600 (12%)
Total Spear Yield (kg/ha)	2,500 (60 days)	2,100 (48 days)	3,100 (59 days)
Spear Yield per Plant (kg)		0.119 (6)	0.176 (8)
Fern Yield (kg/ha)	Average	5,910	3,000
Root Structure (kg/ha) (0.28 kg/plant)		4,930	4,930
Root CHO Content (mg/g)			
Pre-harvest		394	395
End of Harvest		278	286
Fern Established		242	251
Peak Fern		367	436
End of Season		434	556
Root CHO (kg/ha)			
Pre-harvest		3,200 ???	3,200 ???
Spear Yield/Root CHO		0.66	0.97
Comments	* Phytophthora in 2003	* Low yield, short harvest, 80% thin spears * Moderate Stemphyllium, slight beetle * Variable roots	* Even, good yield * Average fern growth, affected by drought * Variable roots, deep, healthy, some hollow

Summary: Established crop, average root system size, plants lost early (Phytophthora?), then population OK, generally average to strong (too strong?) fern growth with few problems, good CHO pattern.

Crop: S2

Region: South **Cultivar:** Venlim
Planted: 1996 **Planted as:** Transplants **Planted Population:** 22,2500 plants per ha

	2004	2005	2006
Plants per ha (% lost)		17,130 (27%)	15,100 (32%)
Total Spear Yield (kg/ha)	4,200 (60 days)	5,300 (56 days)	4,700 (52 days)
Spear Yield per Plant (kg)		0.309 (15)	0.311 (15)
Fern Yield (kg/ha)	Average	5,710	3,940
Root Structure (kg/ha) **(0.37 kg/plant)**		6,320	5,440
Root CHO Content (mg/g) **Pre-harvest** **End of Harvest** **Fern Established** **Peak Fern** **End of Season**		 459 303 300 408 513	 444 312 291 ***559*** 547
Root CHO (kg/ha) **Pre-harvest**		 5,360	 4,340
Spear Yield/Root CHO		0.99	1.08
Comments	* Phytophthora	* Slight Phytophthora * Strong fern growth, but missing plants and some pests, disease and waterlogging * Mixed roots, many healthy and also many hollow	* Good yield, vigorous, double rows * Average fern growth, but missing plants and some weeds * Mixed roots, some close to surface, many healthy and also many hollow

Summary: Oldest crop, good root system size, holding up well for its age, not declining except for significant plant loss, some Phytophthora, still vigorous fern growth and spear yield, perhaps a cultivar effect, CHO pattern looks good except one anomalous result late in 2006.

Crop: S3

Region: South
Planted: 1998 **Planted as:** Transplants **Planted Population:** 21,700 plants per ha

	2004	2005	2006
Plants per ha (% lost)		19,310 (11%)	17,900 (17%)
Total Spear Yield (kg/ha)	3,800 (58 days)	3,600 (57 days)	3,200 (47 days)
Spear Yield per Plant (kg)		0.186 (9)	0.179 (9)
Fern Yield (kg/ha)	Average	2,820	1,400
Root Structure (kg/ha) (0.55 kg/plant)		10,620	9,620
Root CHO Content (mg/g)			
Pre-harvest		497	521
End of Harvest		354	335
Fern Established		302	269
Peak Fern		398	464
End of Season		490	485
Root CHO (kg/ha)			
Pre-harvest		10,500	10,470
Spear Yield/Root CHO (Plant efficiency)		0.34	0.31
Comments	* Slight beetle	* Some weeds * Average fern growth, some decline, some pests, weeds and disease * Variable roots	* Some weeds and Phytophthora * Stunted fern growth, dry soil, new ferns even at peak, severe beetle causing defoliation * Big root system, about 10% hollow

Summary: Established crop with one of the largest root systems, some population loss, CHO pattern looks good except for effects of dry conditions and late defoliation in 2006, spear yield lower than most indicators would suggest.

Crop: S4

Region: South
Planted: 2002 **Planted as:** Crowns **Planted Population:** 22,500 plants per ha

	2004	2005	2006
Plants per ha (% lost)		21,150 (6%)	21,150 (6%)
Total Spear Yield (kg/ha)	No harvest	4,400 (56 days)	4,400 (49 days)
Spear Yield per Plant (kg)		0.208 (10)	0.208 (10)
Fern Yield (kg/ha)	Strong	3,170	3,020
Root Structure (kg/ha) **(0.39 kg/plant)**		8,200	***8,200*** (roots still growing)
Root CHO Content (mg/g) **Pre-harvest** **End of Harvest** **Fern Established** **Peak Fern** **End of Season**		 472 346 255 516 506	 509 338 236 491 530
Root CHO (kg/ha) **Pre-harvest**		 7,150	 ***8,700***
Spear Yield/Root CHO		0.62	0.51
Comments	* Beetle and rubble in crop	* Slight Phytophthora during harvest * Average fern growth, some toppling and secondary growth in August, severe Stemphylium * Roots healthy	* Beetle, slugs and Stemphylium during harvest * Moderate Stemphylium, ground hard and dry at fern establishment, strong fern growth but still new ferns coming at peak * Numerous healthy roots

Summary: Establishing, young, healthy, vigorous crop with good population, limited by problems during fern growth (pests, Stemphylium, new late ferns), CHO pattern looks good except Stemphylium effect late in both seasons, especially bad in 2005.

Crop: W1

Region: West
Planted: 2003 **Planted as:** Crowns **Planted Population:** 24,000 plants per ha

	2004	2005	2006
Plants per ha (% lost)		24,000 (0%)	19,440 (19%)
Total Spear Yield (kg/ha)	3,300 (50 days)	6,600 (89 days)	5,000 (63 days)
Spear Yield per Plant (kg)		0.275 (14)	0.257 (13)
Fern Yield (kg/ha)	Average	1,490	4,720
Root Structure (kg/ha) **(0.21 kg/plant)**		5,030	***4,140*** (roots still growing)
Root CHO Content (mg/g) **Pre-harvest** **End of Harvest** **Fern Established** **Peak Fern** **End of Season**		 511 295 281 391 457	 435 277 334 530 575
Root CHO (kg/ha) **Pre-harvest**		 5,250	 ***3,190***
Spear Yield/Root CHO		1.26	1.57
Comments	* Polythene covers, Stemphyllium and beetle	* Polythene covers, harvest started 4 weeks early and ended 1 week later, crop stressed at end, water in gullies * Weak fern growth, some fern damage, herbicide, pests and disease * Roots healthy	* Polythene covers but later start, early finish and lower yield than other crops – lower yield * Good fern growth after early stop, mod Stemphylium * Roots healthy

Summary: Establishing, young, healthy, vigorous crop, heavy early harvests extended with use of polythene, losing plants early, CHO pattern looks good except poor recovery with weak fern growth following the extended harvest in 2005, much better recovery following shorter harvest in 2006.

Crop: W2

Region: West
Planted: 1999 **Planted as:** Transplants **Planted Population:** 20,000 plants per ha

	2004	2005	2006
Plants per ha (% lost)		18,800 (6%)	11,400 (43%)
Total Spear Yield (kg/ha)	1,200 (55 days)	2,800 (59 days)	1,200 (58 days, tips)
Spear Yield per Plant (kg)		0.149 (7)	0.105 (10 (@ 10))
Fern Yield (kg/ha)	Weak	2,830	2,020
Root Structure (kg/ha) (0.32 kg/plant)		5,940	3,550
Root CHO Content (mg/g)			
Pre-harvest		494	647
End of Harvest		341	397
Fern Established		271	307
Peak Fern		459	***559***
End of Season		614	543
Root CHO (kg/ha)			
Pre-harvest		5,800	6,510
Spear Yield/Root CHO		0.48	***0.37***
Comments	* Small spears * Weak crop since establishment as transplants	* Many small spears * Average fern growth, slight pests and disease, many plants lost * Variable roots	* 75% small spears * Weak fern growth, slight Stemphylium, moderate beetle and rust, many plants lost

Summary: Established crop in classical decline, weak fern growth, many plants lost, low spear yields, CHO pattern looks good except late in 2006.

Crop: W3

Region: West
Planted: 1999 **Planted as:** Transplants **Planted Population:** 25,000 plants per ha

	2004	2005	2006
Plants per ha (% lost)		24,000 (4%)	14,000 (40%, est)
Total Spear Yield (kg/ha)	2,300 (55 days)	2,400 (58 days)	1,800 (45 days)
Spear Yield per Plant (kg)		0.100 (5)	0.128 (6)
Fern Yield (kg/ha)	Weak	2,080	1,120
Root Structure (kg/ha) **(0.24 kg/plant)**		5,840	3,400
Root CHO Content (mg/g) **Pre-harvest** **End of Harvest** **Fern Established** **Peak Fern** **End of Season**		 476 287 289 426 496	 547 262 280 463 ***652***
Root CHO (kg/ha) **Pre-harvest**		 5,300	 ***4,510***
Spear Yield/Root CHO		0.45	***0.40***
Comments	* Small spears, beetle	* Slow harvest start, otherwise OK * Average fern growth, some weeds * Variable roots	* Many small spears * Weak fern growth, moderate beetle, crop in decline, plants lost

Summary: Established crop in classical decline, weak fern growth, many plants lost, low spear yields, CHO pattern looks good except high late in 2006 and low at the end of each harvest.

Crop: W4

Region: West **Cultivar:** Backlim
Planted: 2001 **Planted as:** Transplants **Planted Population:** 22,200 plants per ha

	2004	2005	2006
Plants per ha (% lost)		22,200 (0%)	19,800 (11%)
Total Spear Yield (kg/ha)	4,500 (57 days)	5,100 (51 days)	4,400 (46 days)
Spear Yield per Plant (kg)		0.230 (11)	0.222 (11)
Fern Yield (kg/ha)	Average	4,360	4,190
Root Structure (kg/ha) **(0.53 kg/plant)**		11,690	10,450
Root CHO Content (mg/g) **Pre-harvest** **End of Harvest** **Fern Established** **Peak Fern** **End of Season**		 551 ***365*** 285 460 554	 587 ***475*** 281 488 549
Root CHO (kg/ha) **Pre-harvest**		 14,340	 14,850
Spear Yield/Root CHO		0.36	0.28
Comments	* Stemphylium high and weeds during fern growth	* No harvest problems * Strong fern growth, slight pests and disease, no plants lost, patchy weeds * Healthy roots	* No harvest problems * Strong fern growth, mod Stemphylium, * Many thick healthy roots, quite deep

Summary: Established, healthy, vigorous crop with the largest root system, few problems, minor plant loss so far, CHO pattern looks good except end of harvest values are high, perhaps not fully exploited, could harvest more.